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AN AFFORDABLE, TWO-DIMENSIONAL, HIGH-RESOLUTION ACOUSTIC IMAGING ARRAY

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14. ABSTRACT
The design, fabrication, and measured results for a prototype, two-dimensional, ultrasonic imaging array are described. The active sensor consists of virtually three layers: (1) a piezoelectric 1-3 composite layer, (2) a flex-circuit component, and (3) a special adhesive that joins them. The sensor construction utilizes electroplated, injection-molded 1-3 piezocomposite as the active layer. Four multi-layer, acoustically thin flex-circuits provide the electrical connections required for addressing the 468 individual array elements. Of key importance to the fabrication process is the use of a composite, B-stage, adhesive film layer that combines both conductive and non-conductive regions in a pattern-specific orientation within the plane comprising the bond line interface. The conductive regions of the adhesive film are registered with respect to the electroplated sections on both the flex-circuit and the 1-3 piezocomposite substrate. The transducer array is a reciprocal device operable in both transmit and receive modes. Measured results include individual element and array calibrations (i.e., receive responses, beam patterns, and relative phase).

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ABSTRACT

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ADMINISTRATIVE INFORMATION

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ACKOWLEDGMENTS

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INTRODUCTION

The development of a low-cost, two-dimensional imaging array is described in this memorandum. The technical objective of this work was to utilize some of the new transducer materials and develop an array fabrication technology for future sonar applications. The device constructed represents a one of a kind prototype and, although there is room for improvements, the overall goal of combining these new materials in a process that would lend itself to high volume production was met.

FABRICATION OVERVIEW

The transducer consists of virtually three layers: an active layer, a flex-circuit, and a specially designed adhesive film. The active material, shown in figure 1, was an electroplated, injection-molded 1-3 piezocomposite (manufactured by Materials Systems Inc., 521 Great Rd, Littleton, MA 01460, (508) 486-0404). The specific configuration utilized PZT-5H rods aligned vertically within a syntactic foam-like matrix material. The substrate dimensions were approximately 0.305 x 0.305 x 0.003 meters (12.0 x 12.0 x 0.125 inches). The array substrate's lateral dimensions were chosen to follow the outline of the current Mk 48 torpedo homing array aperture. The copper plating allowed the formation of 468 positive electrode surfaces and a single common electrode surface on the opposite side. Each element was 10.4 x 10.4 mm (0.41 x 0.41 inch) with a center-to-center spacing of 11.2 mm (0.44 inch).

The photograph in figure 2 shows the two sides of the flex-circuit component (manufactured by Tech Etch Inc., 45 Aldrin Rd, Plymouth, MA 02360, (508) 747-0300). Each flex-circuit addresses 117 elements (one quarter of the total array). Each of the 117 traces carries signals from the plated pads on one surface to the end terminations on the opposite surface via a plated through-hole located in the center of each pad as shown. These 117 traces are abutted on each side by a shielding trace that is grounded to minimize interelement electrical crosstalk.

Figure 3 shows the four flex-circuit components bonded to the aluminum vehicle bulkhead. The lamination of the flex-circuit to the bulkhead was accomplished using a non-conductive B-stage adhesive film (manufactured by A.I. Technologies Inc., 9 Princess Rd, Lawrenceville, NJ 08648, (609) 896-3838). (B-stage is the condition where the constitutive parts of the epoxy have been combined and the material is stored at low temperatures until it is used. Upon melting, the material will liquefy, flow, and cure.) The machined slots allow passage of the flex-circuits into the vehicle's interior. These slots are then filled with a room temperature cure rubber compound prior to encapsulating the array.

Figure 4 is a photograph of the special composite adhesive laid over the injection-molded 1-3 array substrate. This specially designed adhesive consists of B-staged conductive and

non- conductive epoxies, within the same sheet of film. The conductive epoxy provides the electrical connections between the plated array electrodes and the copper pads of the flex circuit. The non-conductive portion provides additional adhesion and also fills in the regions around the conductive bond area to prevent silver migration. The pattern of the conductive and non-conductive regions is user-specific and may be manufactured to high tolerances, i. e., ± 0.076 mm (±0.003 inch).

Figure 5 shows the composite adhesive film being trimmed to final size. Figure 6 shows one of the adhesive films being positioned prior to lamination. Note that the flex-circuit terminations have been passed behind the bulkhead and the slots have been filled. The 1-3 piezocomposite is ready to be positioned and laminated. Positioning of the array substrate was accomplished using removable pins. Figure 7 is a photograph of the finished array. Four ground wires were attached to the common electrode using conductive epoxy paste, and the array was encapsulated with a room temperature cure polyurethane. The inward side of the vehicle bulkhead and the flex-circuit terminations are shown in figure 8. Figure 9 shows the vehicle section containing the signal conditioning electronics.

MEASURED RESULTS

Using a Hewlett Packard network analyzer and an appropriate probe transducer, the array elements' relative sensitivity and phase responses were characterized in air. Figure 10 shows an overlay of six elements located in the central portion of the array aperture. These data indicate the elements' responses track very well.

Next, the array was acoustically calibrated in Code 80's Acoustic Test Tank. The measurements included receive voltage sensitivity and beam patterns for 30 elements, which was the number of preamplifier channels available within the test vehicle.

Using the 30 preamplifier channels available within the test vehicle, the following acoustic quantities were measured:

1. Free-field voltage sensitivity was measured from 40 to 100 kHz for each of the 30 elements.

2. Beam patterns were measured at 40 kHz and 67 kHz (67 kHz is the array element half-wave spacing).

3. A sum beam at 67 kHz was synthesized using a line of 18 elements across the array diameter.

4. Relative phase was measured between two adjacent elements for two frequency ranges (20 to 50 kHz and 40 to 100 kHz).

Figure 11 shows an overlay of three measured voltage sensitivity response curves. The preamplifier gain was 26 dB, yielding an average individual element sensitivity of -196 dB re μPa. Figures 12 and 13 show overlays of three single-element beam patterns measured at 40 and 67 kHz, respectively. The appearance of lateral mode effects is evident around ±30° in the patterns. The unwanted, non-resonant lateral modes may be considerably reduced by dicing the continuous array surface or by changing the composite matrix material surrounding the PZT rods. Nevertheless, the array may be steered to ± 30° without sacrificing performance, as seen in the sum pattern shown in figure 14. The measured pattern taken at 67 kHz agrees very well with the theoretical pattern for the given line aperture. Figures 15 and 16 show the relative phase for two adjacent array elements when the array is facing the projector (broadside response) for two frequency ranges, 20 to 50 kHz and 40 to 100 kHz, respectively.

SUMMARY

A fabrication process has been successfully implemented to construct a low-cost imaging array. The manufacturing technique relies on state-of-the-art transducer materials and is well suited to automated high-volume production. Because of the reduced number of assembly components, the anticipated assembly labor costs would be significantly reduced compared to other current array fabrication processes. Lastly, it is noted that, although this work addressed the planar case, low-cost cylindrical array geometries could be realized also.

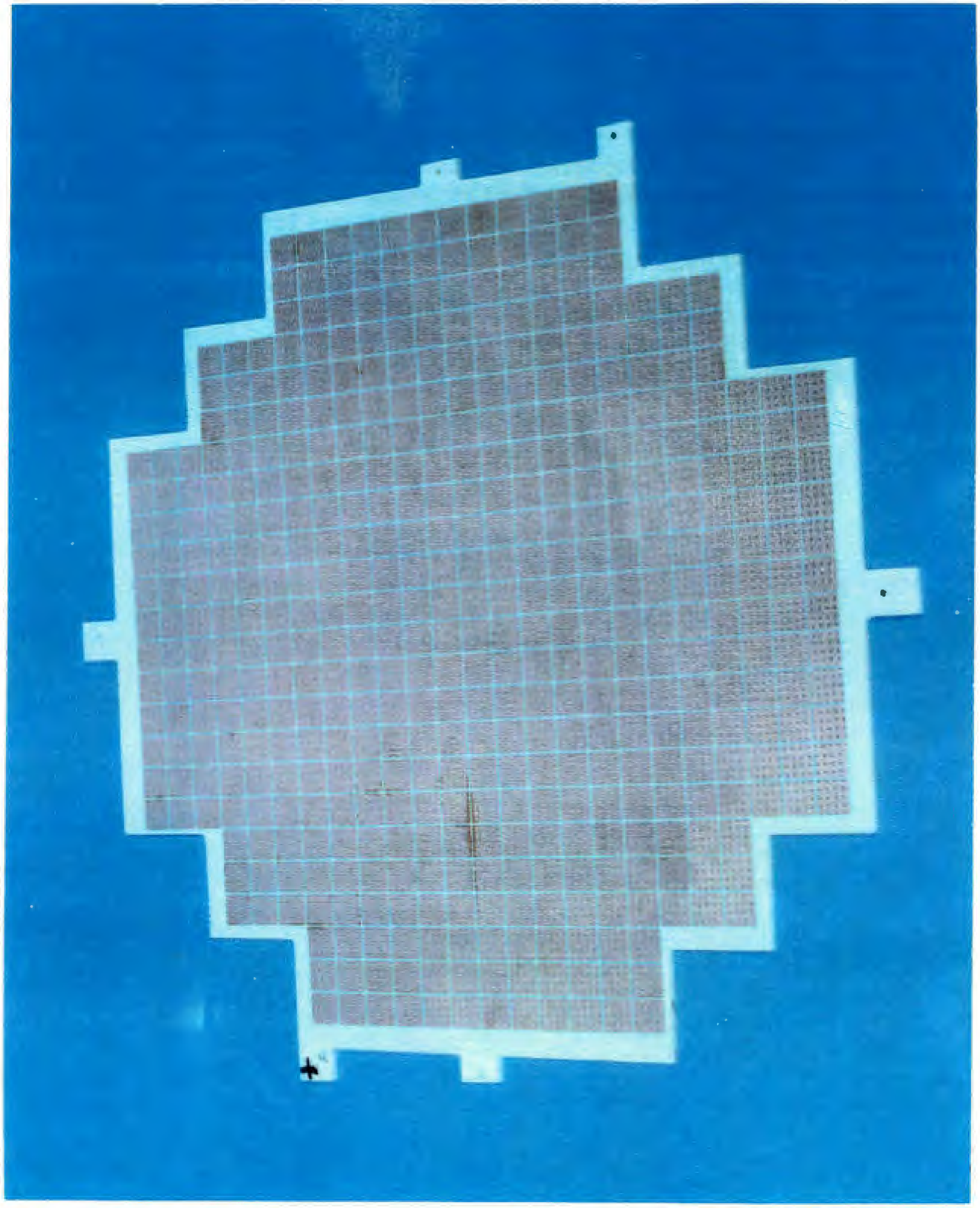


Figure 1a. Positive Electrode Side of 1-3 Piezocomposite Substrate

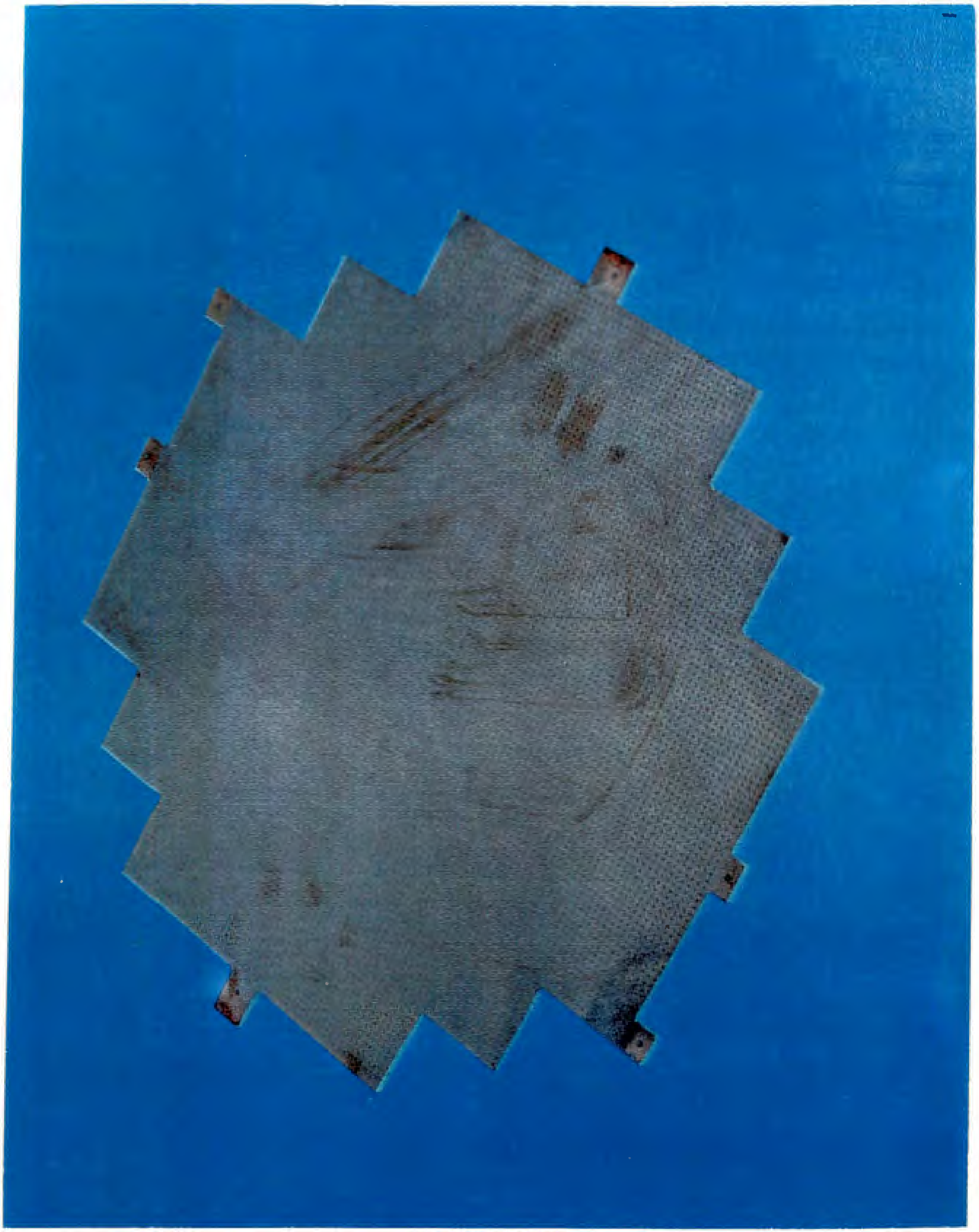


Figure 1b. Common Electrode Side of 1-3 Piezocomposite Substrate

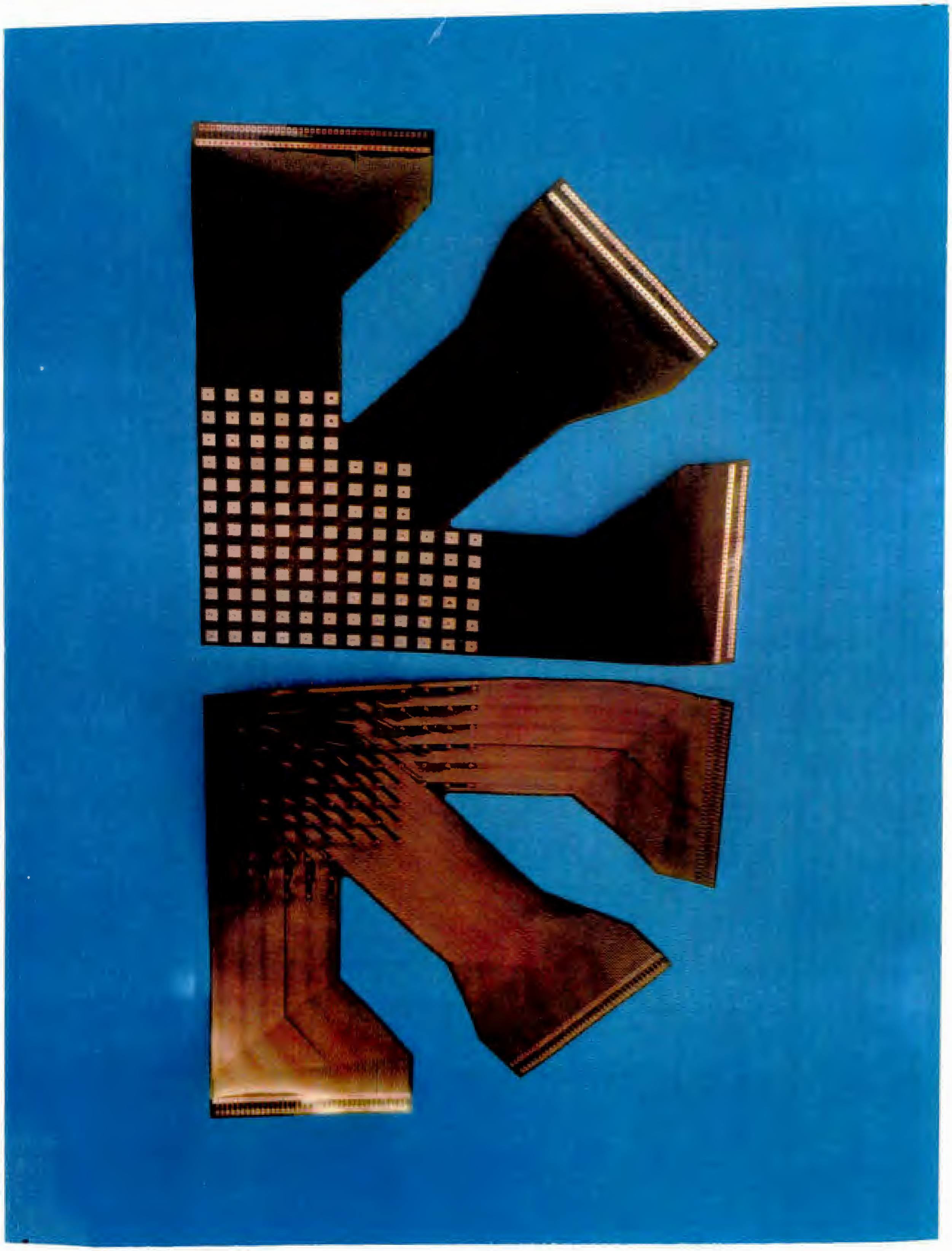


Figure 2. Flex-Circuit Component

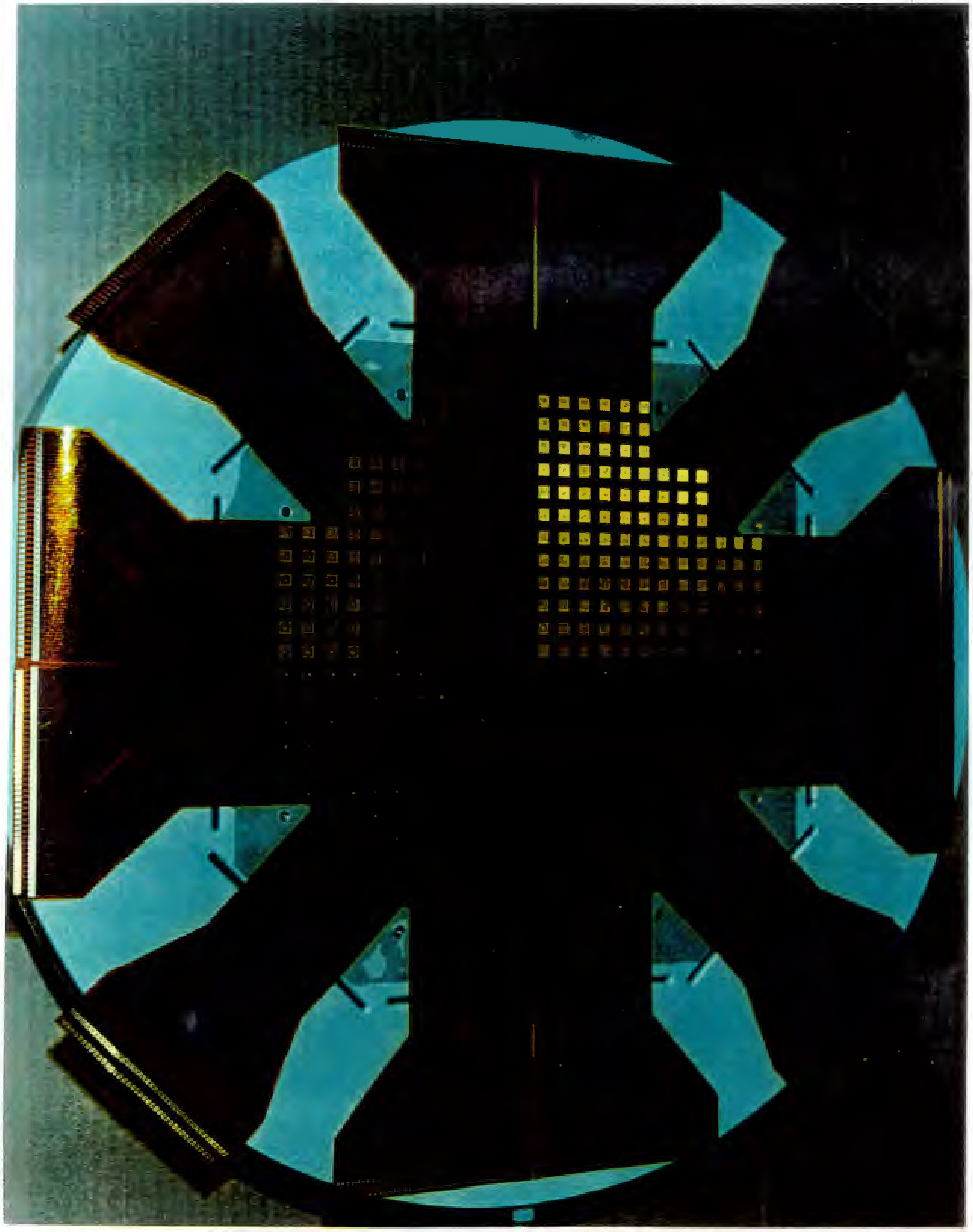


Figure 3. Bonded Flex-Circuits

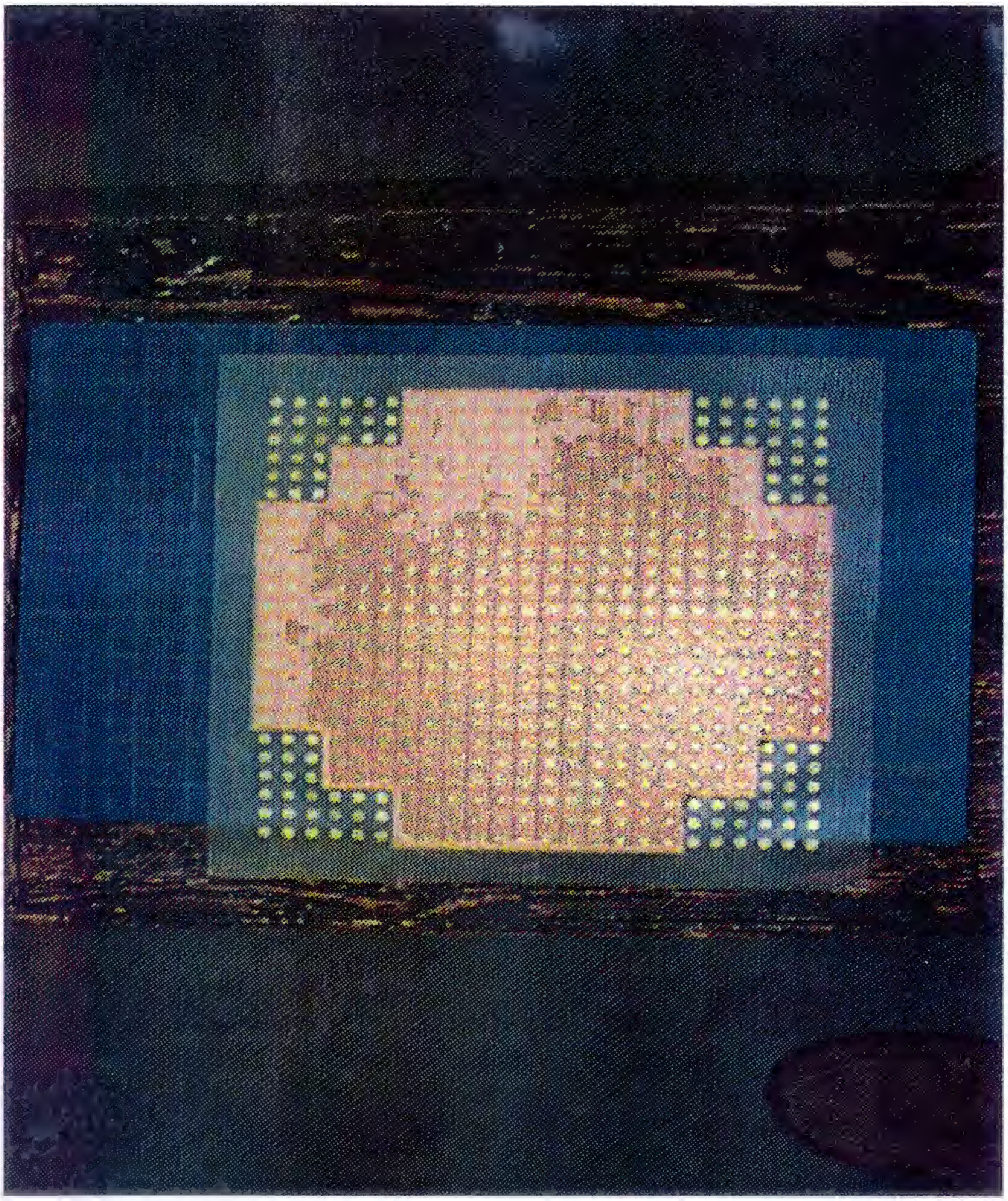
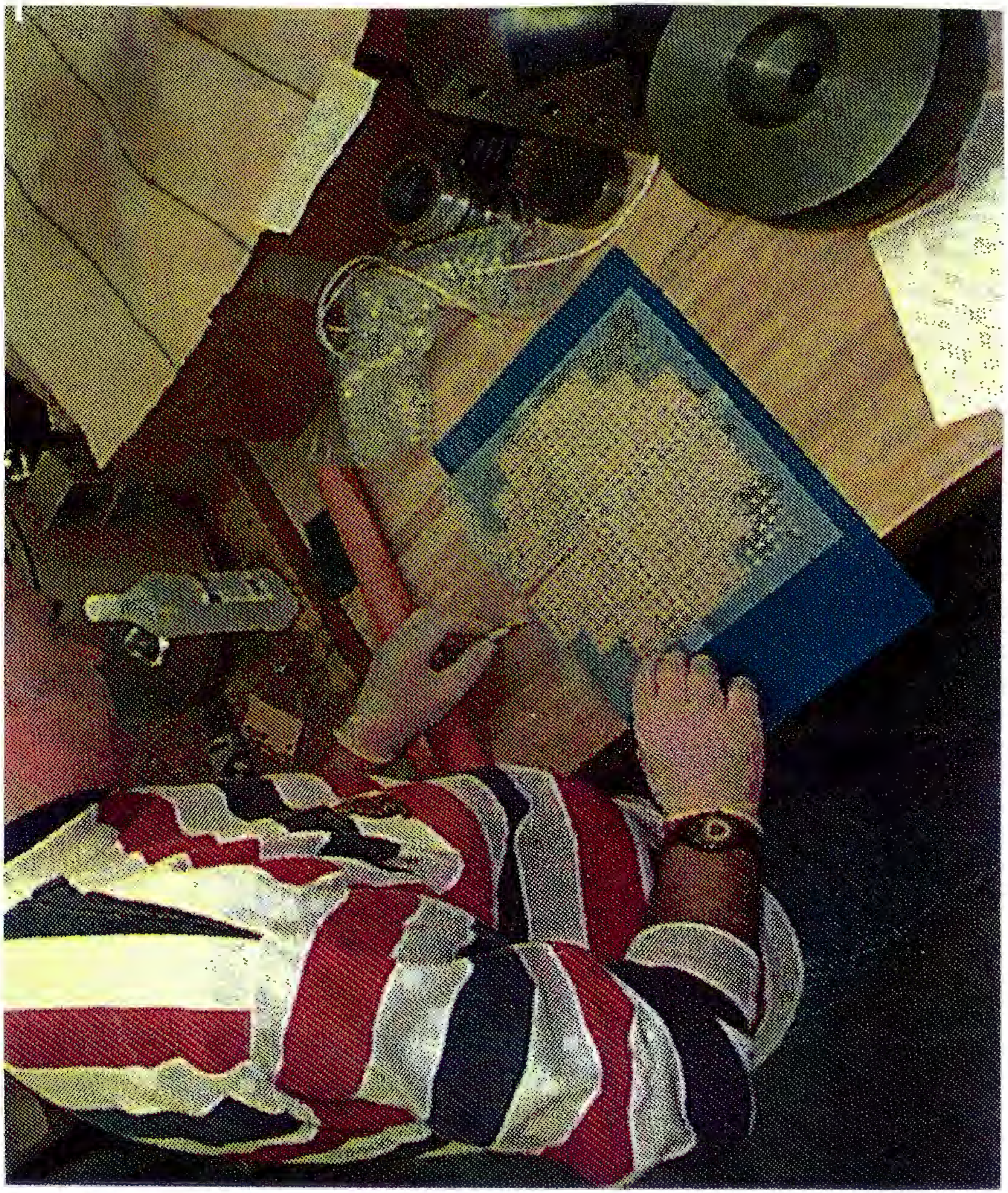


Figure 4. Composite Adhesive Film Overlaid on 1-3 Piezocomposite Substrate 8



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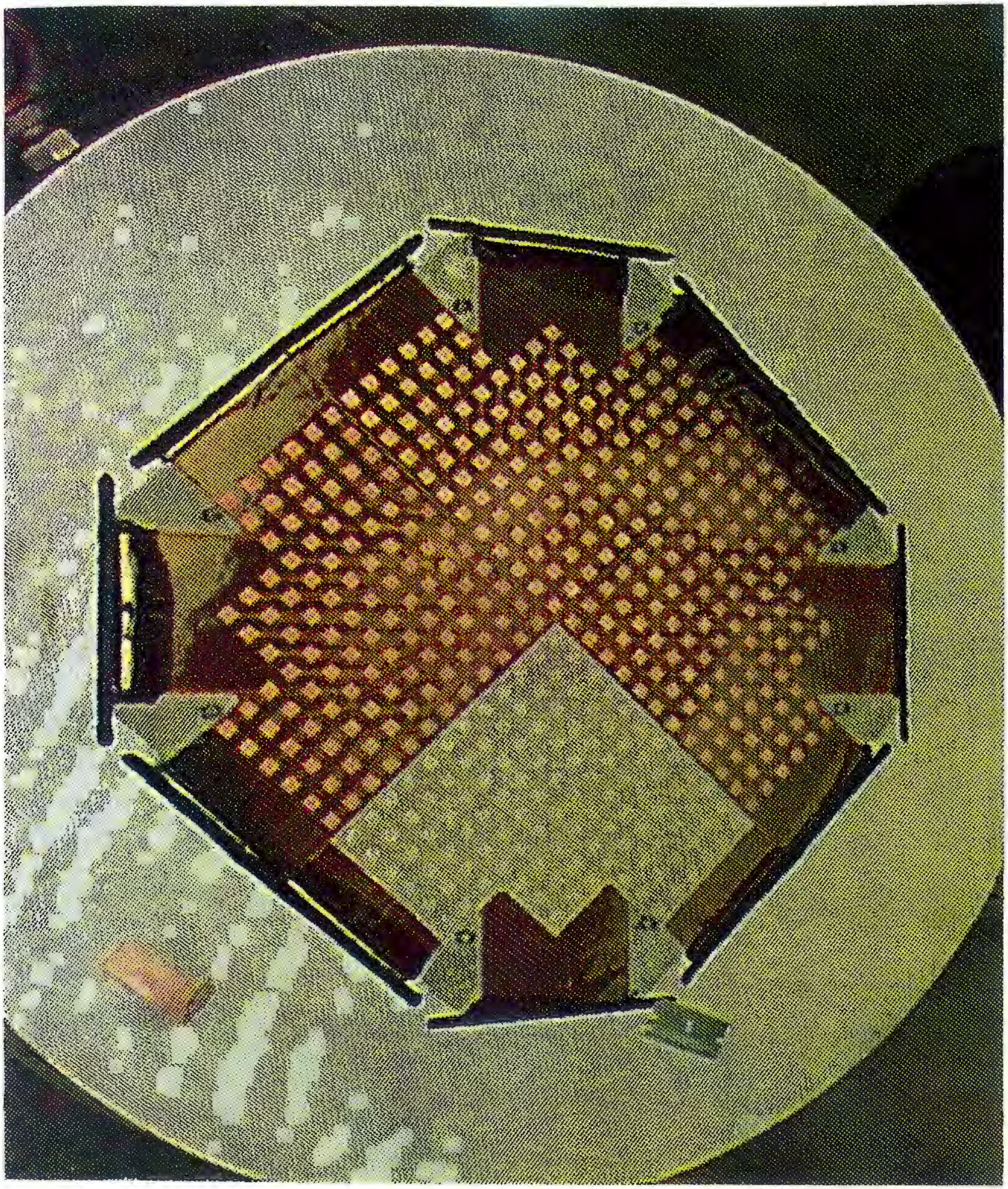
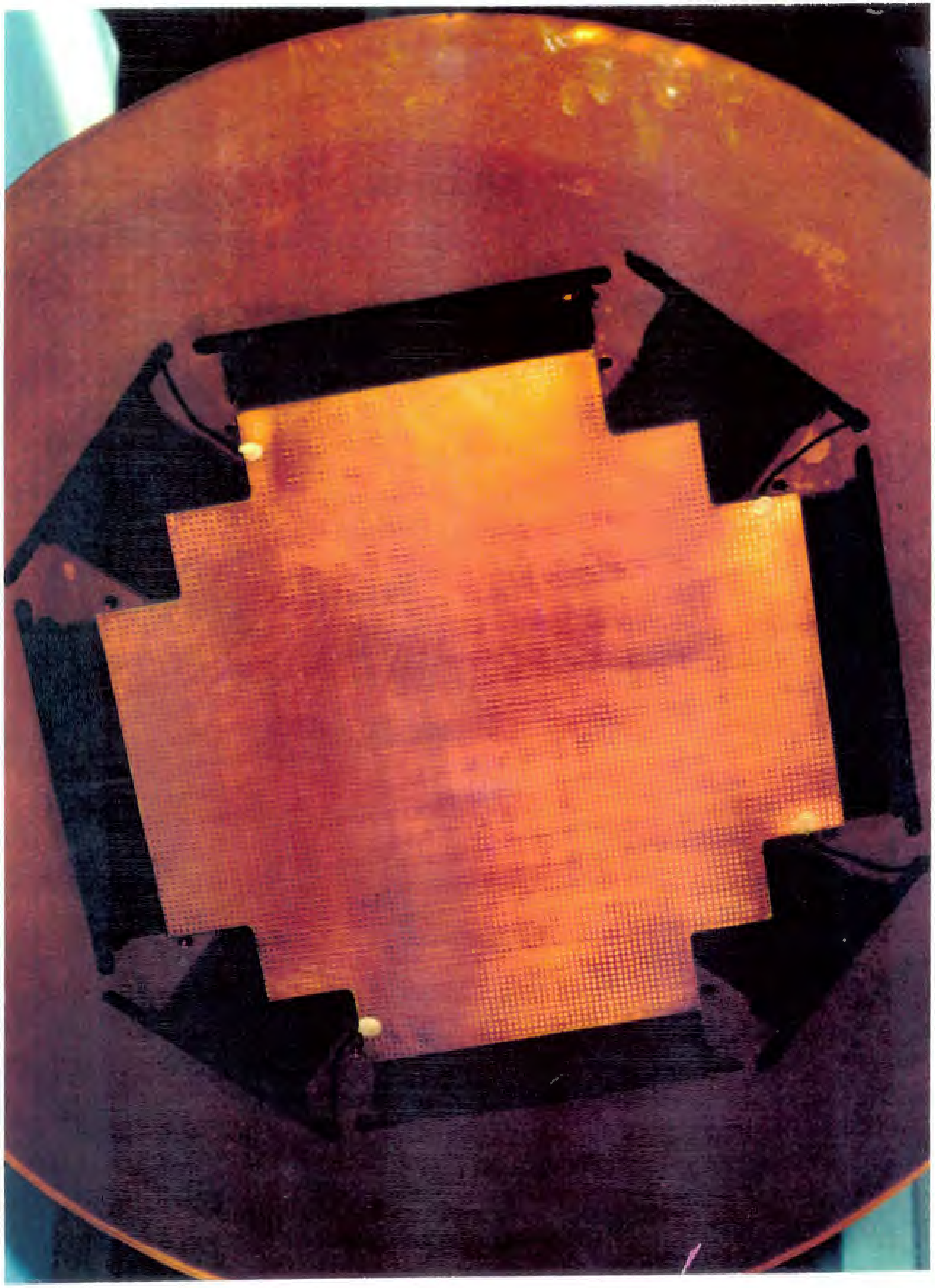


Figure 6. Bonded Flex-Circuits and One of the Composite Adhesive Film Pieces



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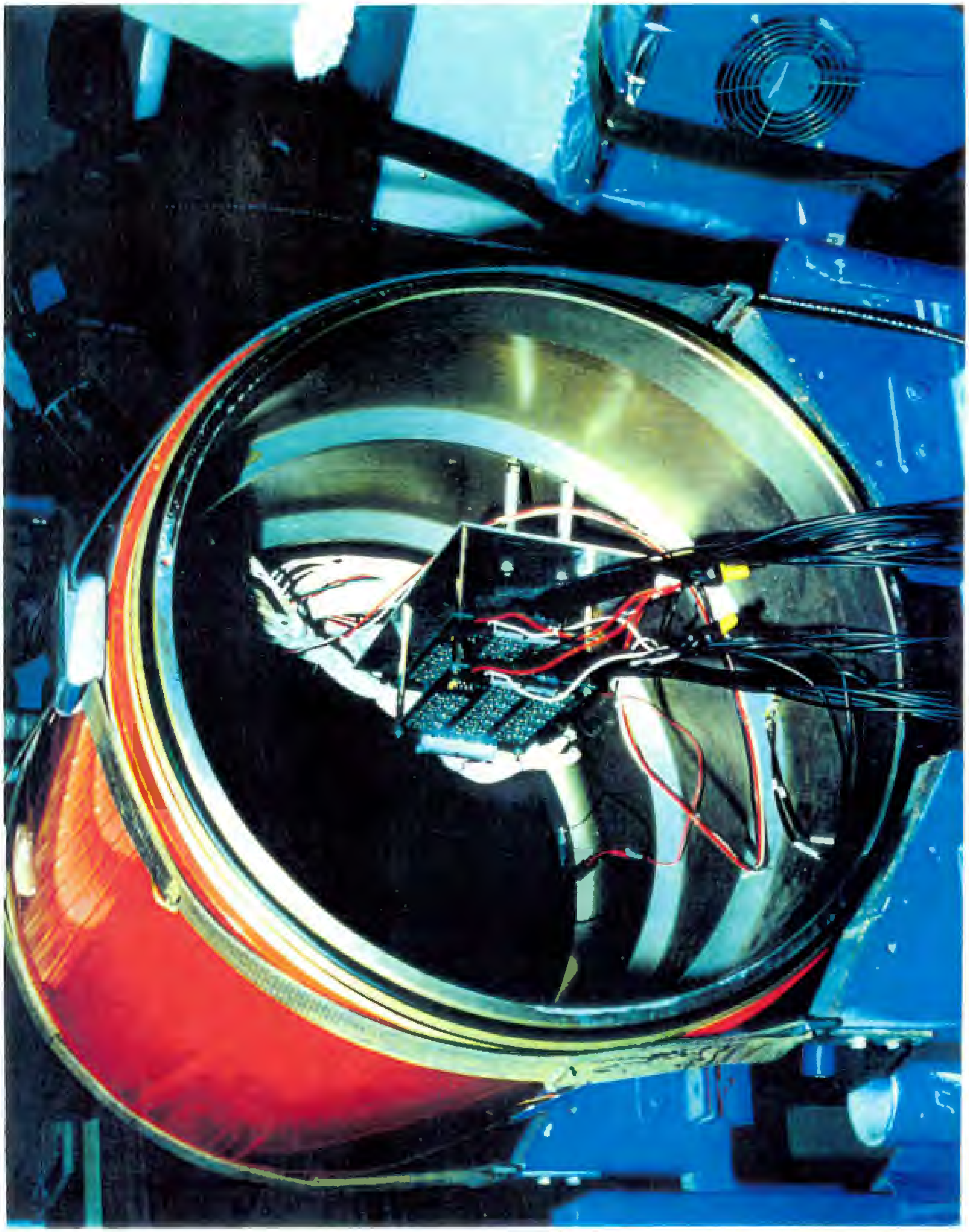

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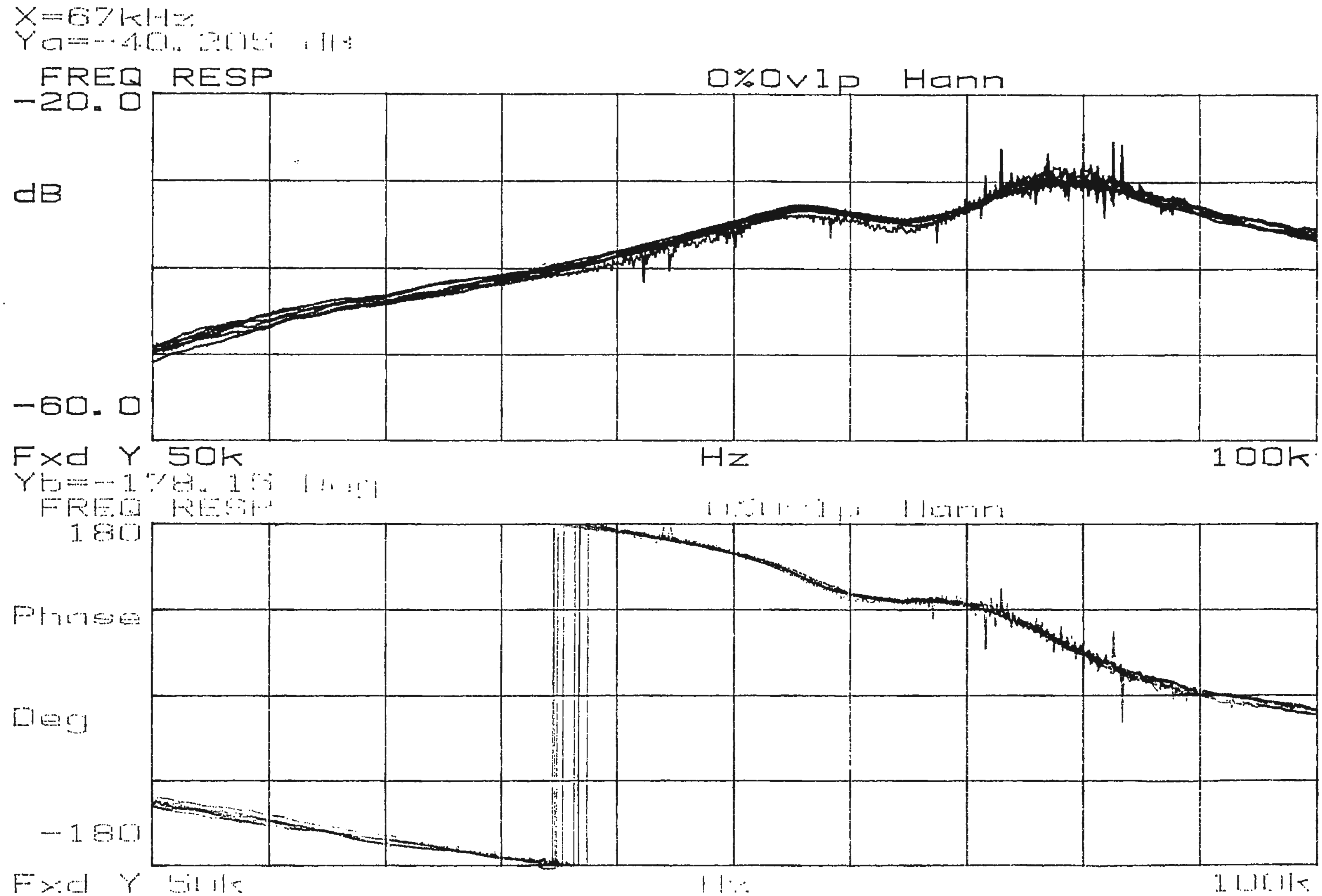

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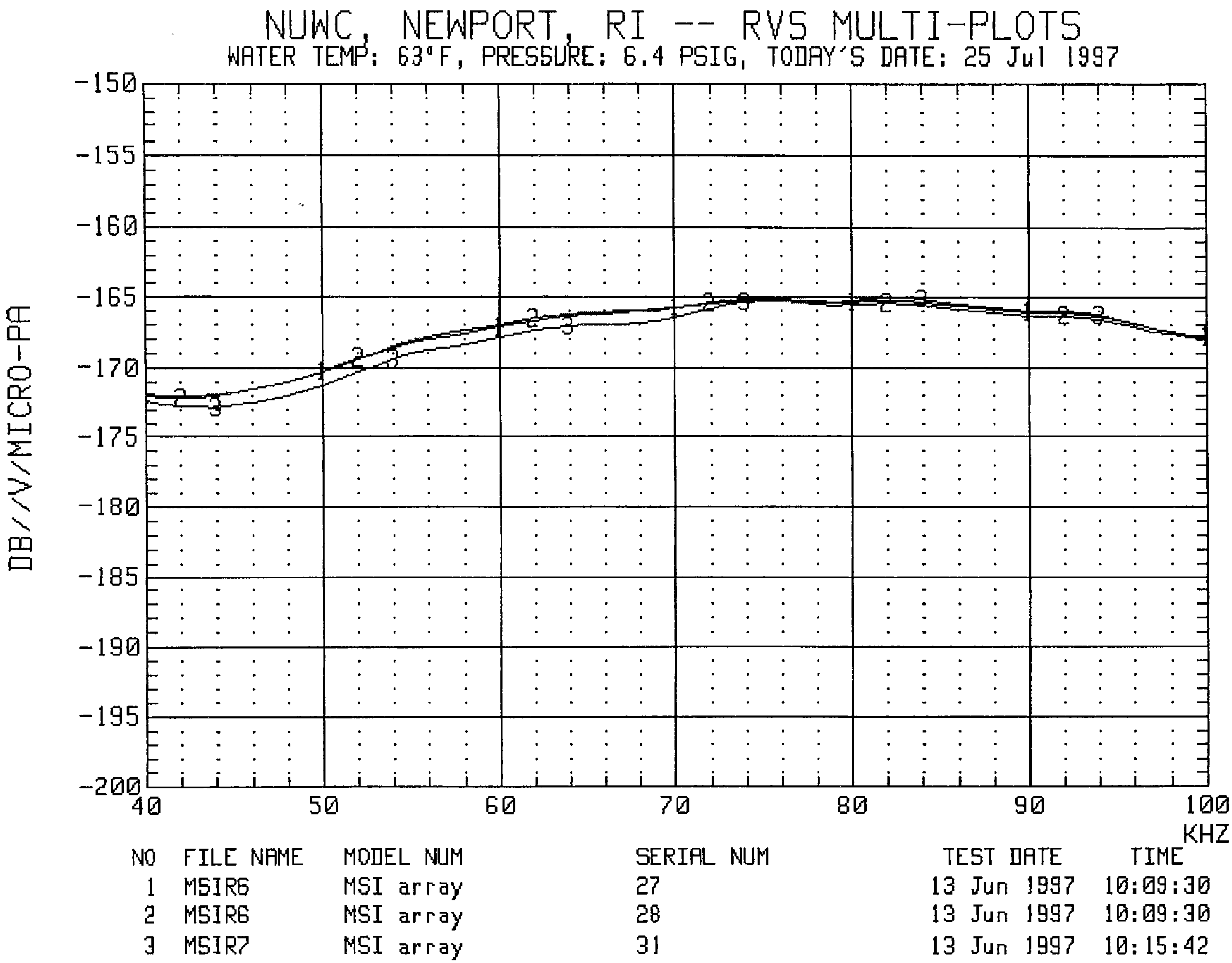

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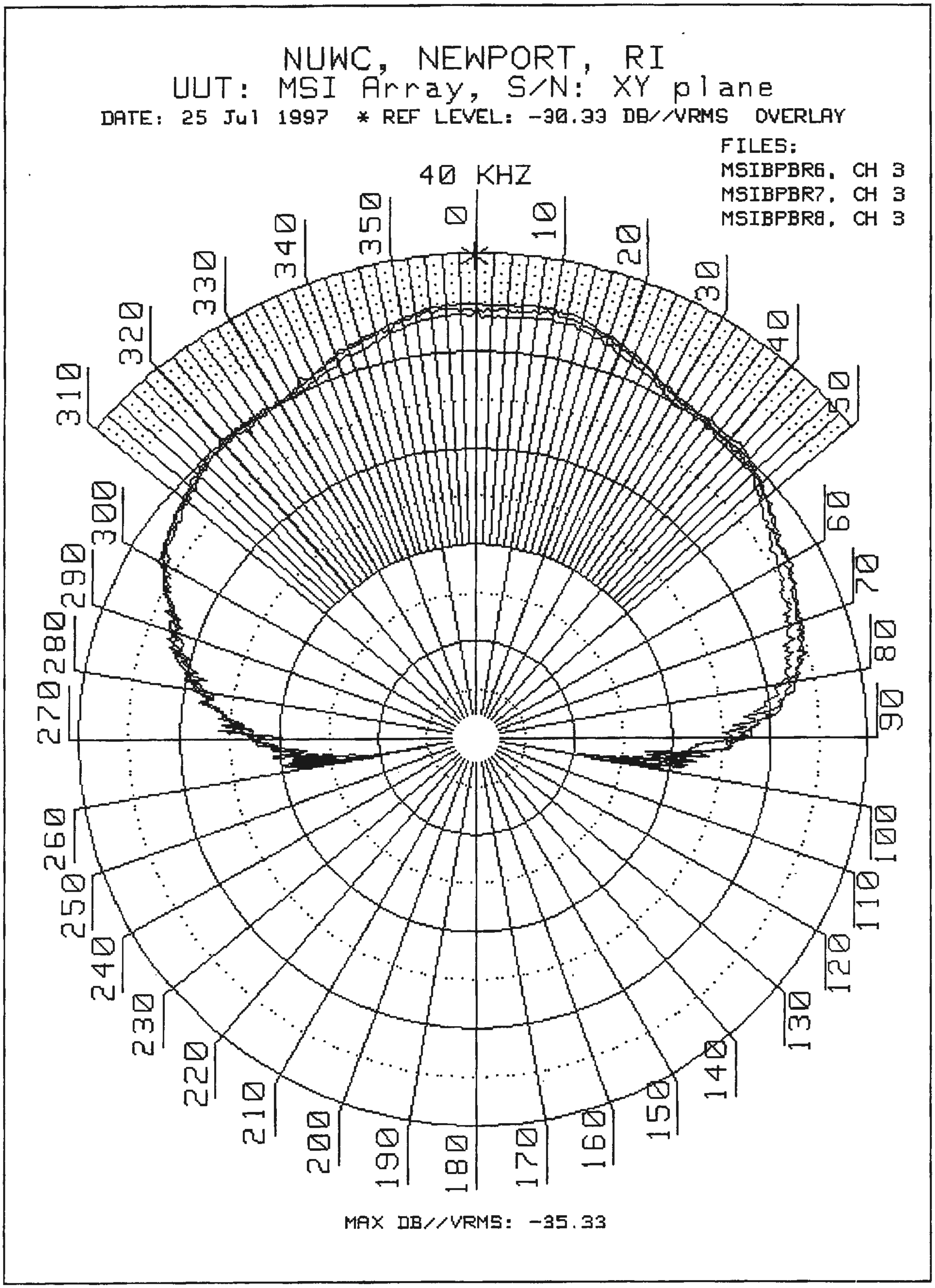

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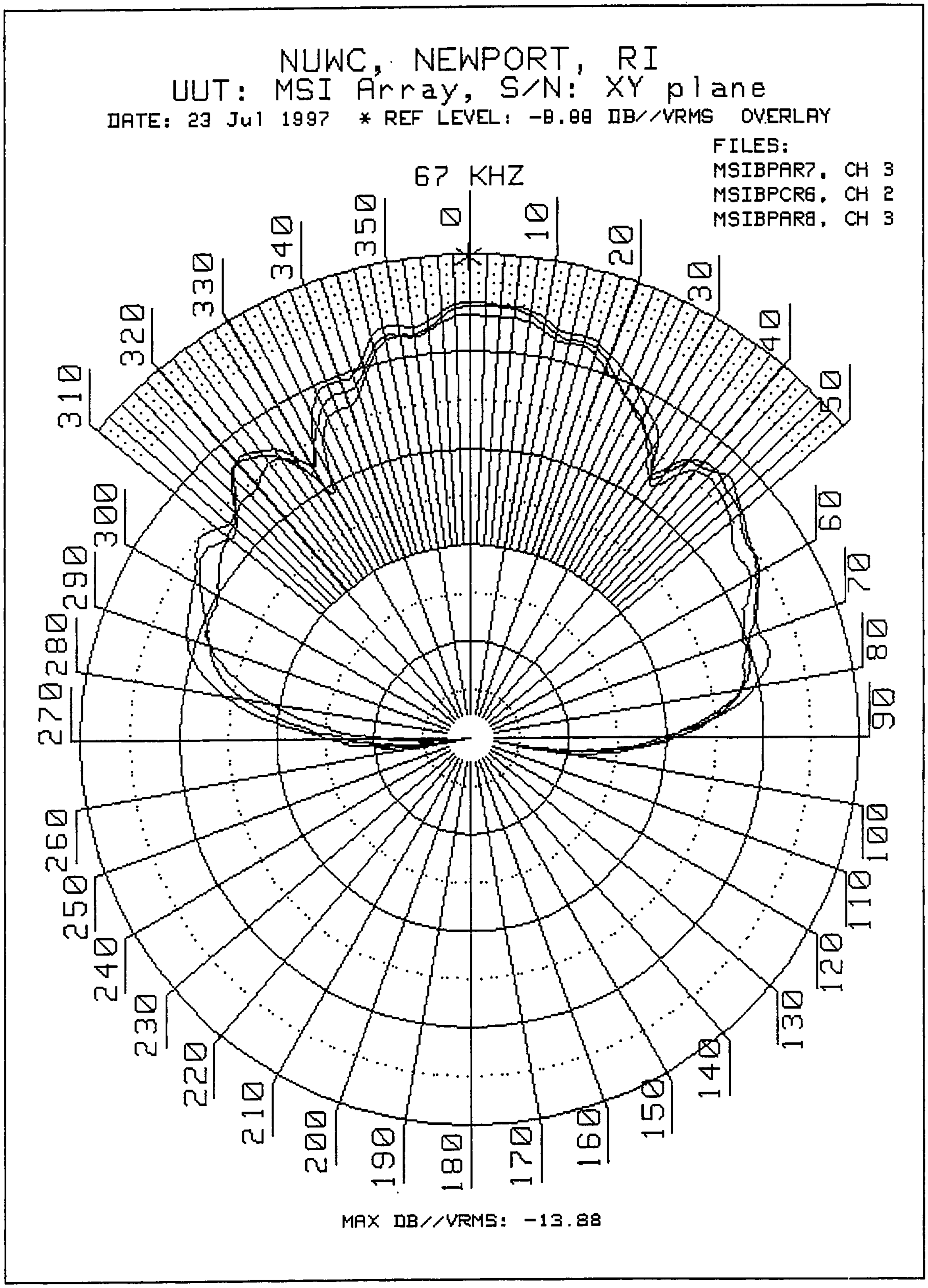

Figure 13. Comparison of Three Single-Element Beam Patterns at 67 kHz

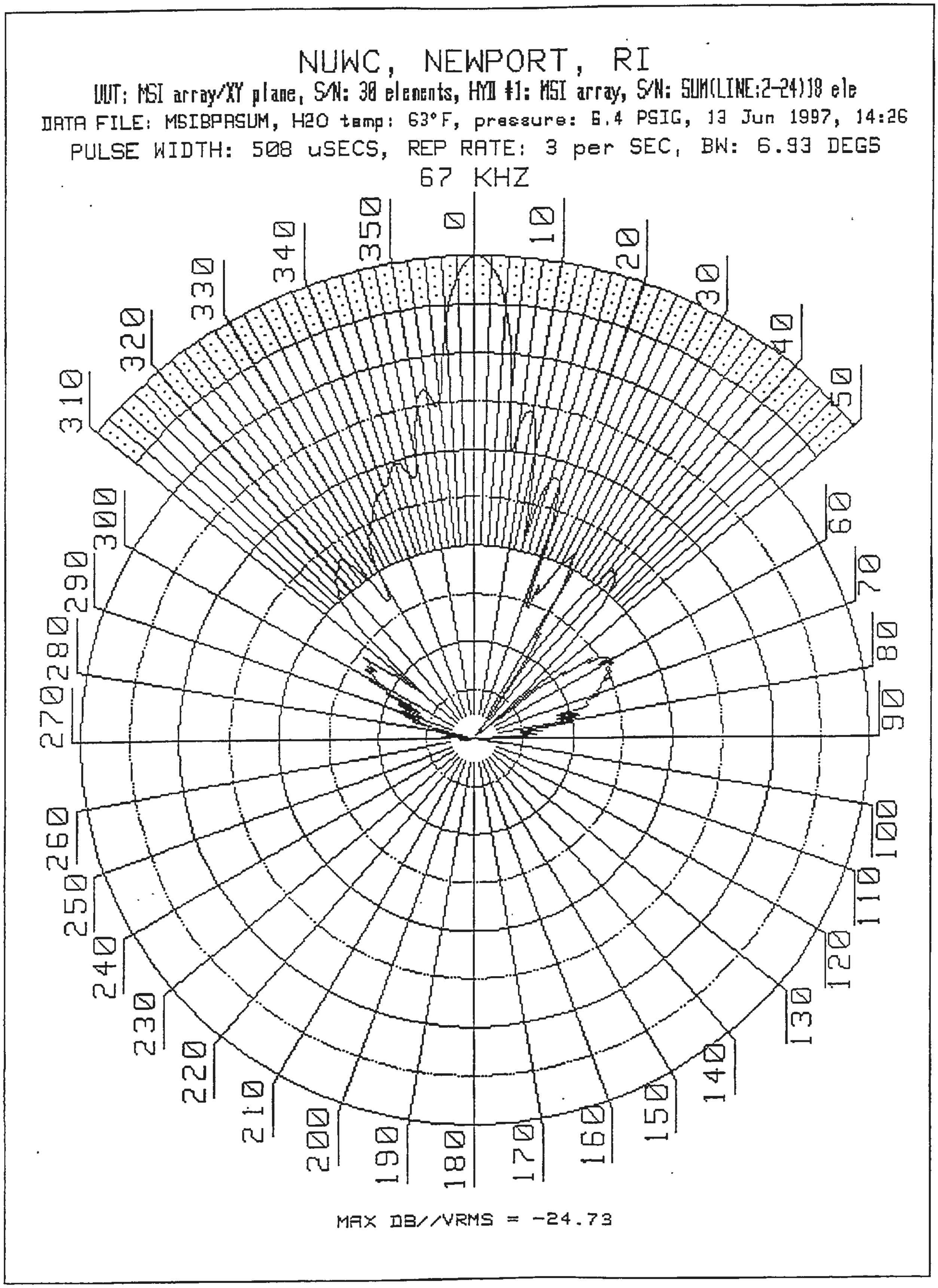

Figure 14. Sum Beam Pattern for 18-Element Line Aperture at 67 kHz

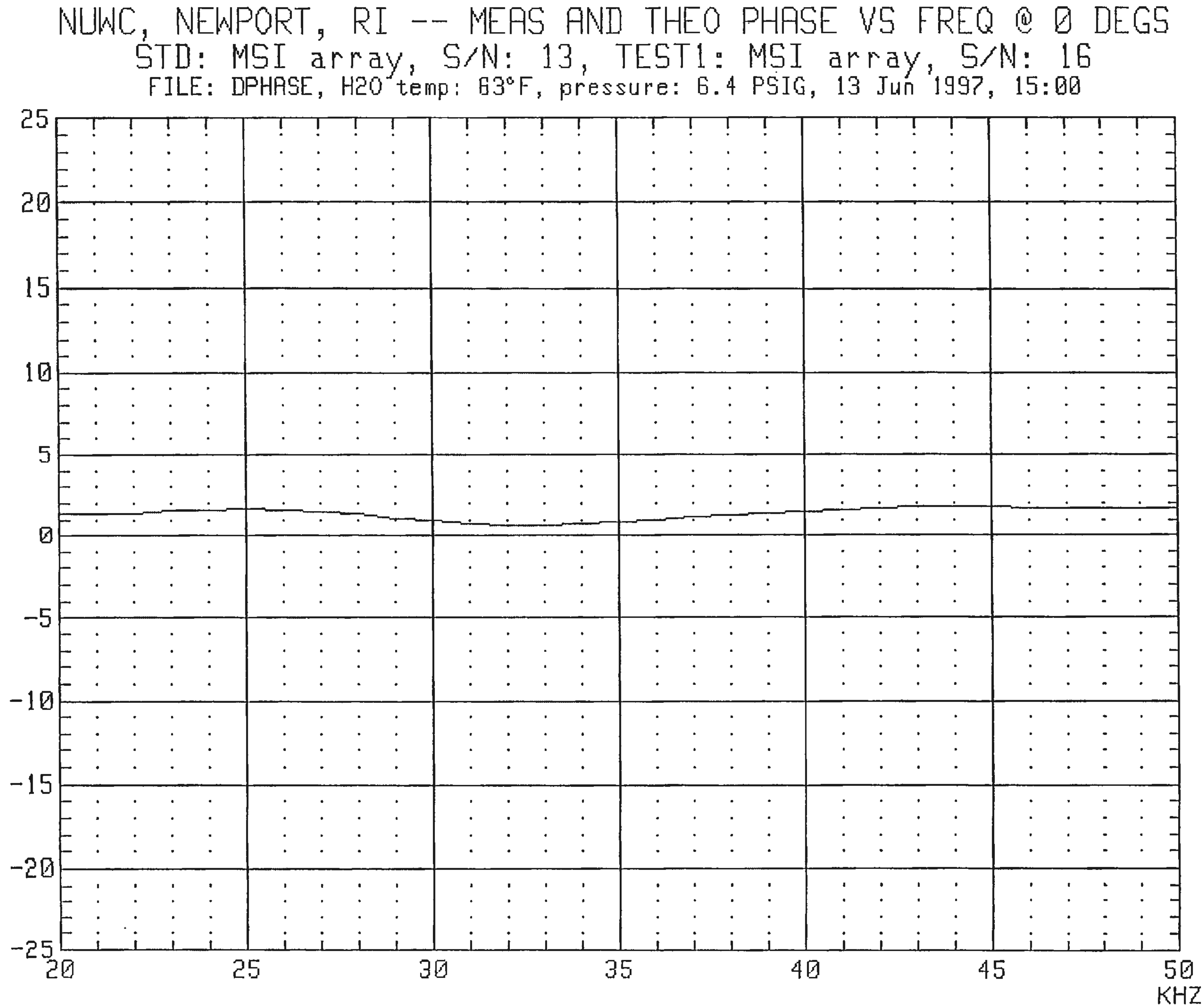

Figure 15. Relative Phase for Two Adjacent Elements (20-50 kHz)

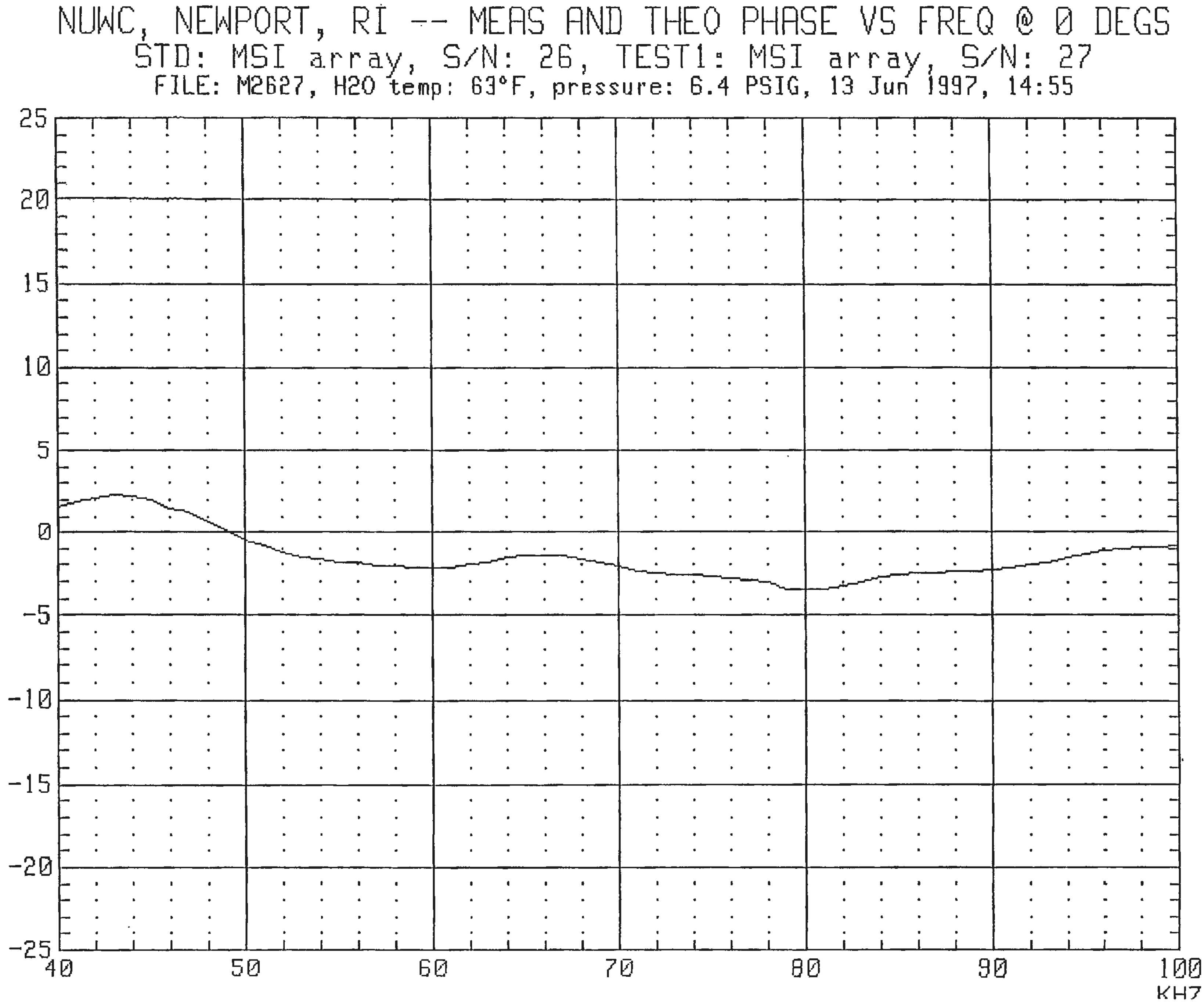

Figure 16. Relative Phase for Two Adjacent Elements (40-100 kHz)

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